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Automated Reconstruction, Execution and Update of Digital Twins for Tunnel Structures

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Tunnels are critical infrastructure assets whose safe operation depends on regular inspection, yet current practice still relies largely on periodic manual patrols in which inspectors visually identify cracks, seepage, spalling and deformations and record them by hand. This process is time-consuming, labour-intensive and strongly dependent on individual experience. Digital Twins (DTs) offer a route to transform it, but their value depends on how efficiently raw field data can be turned into semantically rich, analysable models, and how reliably those models can be kept up to date over the life of the asset.

We propose a framework for the automated reconstruction, execution and periodic update of Digital Twins for tunnel structures, progressing across maturity levels from descriptive and reflective towards predictive twins. Starting from mobile or terrestrial laser scanning point clouds and images, SAM4TUN, built on the Segment Anything Model, performs training-free instance segmentation of tunnel lining components, from which geometric parameters are extracted and a BIM-based digital model is reconstructed automatically. Surface damage is then detected using zero- and few-shot large vision models. A SAM-based panoptic segmentation approach with multi-inference post-processing handles ultra-high-resolution panoramic tunnel images, while DOWSER, a DINO-based one-shot network, recognises water seepage from a single annotated image and around two minutes of development effort with 95% accuracy compared to a fully supervised models. The detected damage is mapped onto the digital model and passed to DEM or IGA analysis to simulate damage propagation in the lining, linking observed condition to structural performance.

The talk will also report on an ongoing project with Network Rail on automating defect detection in operational railway tunnels, including results on real inspection datasets and a web-based interface for integration with existing GIS-based asset management workflows. Together, these developments point towards remote, consistent and data-driven tunnel inspection, in which the digital twin is refreshed with every new survey and supports evidence-based maintenance decisions.

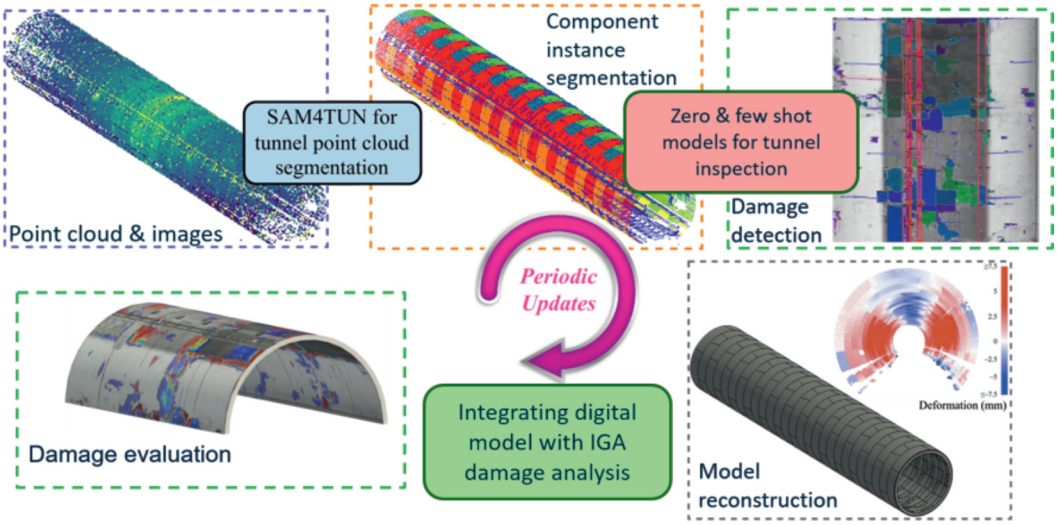


Figure: Framework for the automated reconstruction and periodic update of tunnel Digital Twins: from point clouds and images, through SAM4TUN component instance segmentation and zero- and few-shot damage detection, to model reconstruction and IGA-based damage evaluation.

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